# Second Report of the National Academy of Engineering/National Research Council Committee on New Orleans Regional Hurricane Protection Projects

Committee on New Orleans Regional Hurricane Protection Projects, National Academy of Engineering, National Research Council

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Committee on New Orleans Regional Hurricane Protection Projects

Division on Earth and Life Studies
Division on Engineering and Physical Sciences

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## BACKGROUND

In the wake of the devastation wrought by Hurricane Katrina in late August 2005, the U.S. Army Corps of Engineers established the Interagency Performance Evaluation Task Force (IPET) to address fundamental questions about the performance of the hurricane protection system (HPS) in the New Orleans metropolitan area. Established in October 2005, the IPET is aiming to (1) understand the behavior of the entire New Orleans hurricane protection system in response to Hurricane Katrina and (2) assist in the application of that knowledge to the reconstitution of a more resilient and capable hurricane protection system.[1] Meeting these objectives requires an ambitious, "big picture" study of systems-level features of the New Orleans regional hurricane protection system, and the IPET and its studies will be highly visible and central to planning decisions for New Orleans and southeastern Louisiana for years to come.

The IPET study is focusing its efforts to gather, analyze, and evaluate data on five study objectives:

1. design and status of the hurricane protection system pre-Katrina;
2. storm surges and waves generated by Hurricane Katrina;
3. performance of the hurricane protection system during and after the event;
4. societal-related consequences of Katrina-related damage; and
5. risks to New Orleans and the region posed by future tropical storms.

The IPET study applies to a protection system comprising roughly 284 miles of levees, together with I-walls, other protective structures, and navigation and drainage canals.

[1] Reconstruction activities to prepare for the 2006 hurricane season are ongoing under the auspices of Task Force Guardian, which is a team of staff members from the U.S. Army Corps of Engineers New Orleans District. Task Force Guardian is charged to repair damages to the hurricane and flood protection system in three parishes in the New Orleans region.

These structures have been funded, constructed, and maintained for over 100 years by a combination of federal, state, and local water management entities. The IPET issued interim reports on January 10, 2006, and March 10, 2006 (https://ipet.wes.army.mil/), which represent progress at roughly the 30 percent and 70 percent stages, respectively, of IPET study completion.

In November 2005, Assistant Secretary of the Army for Civil Works John Paul Woodley requested the National Academies to convene a committee of experts to provide an independent review of the IPET studies. The *Committee on New Orleans Regional Hurricane Protection Projects* was appointed in December 2005 under the auspices of the National Academy of Engineering (NAE) and the National Research Council (NRC). (Appendixes A and B contain the committee's statement of task and its membership, respectively. Appendix C lists the external reviewers of this report). This letter report from the committee, the second in a series, evaluates the information presented in the IPET's March 10, 2006, report (or "IPET second report") and identifies issues related to progress toward the IPET study objectives. The report is based on the committee's review of the IPET second report, supplemented with information exchanged with IPET team members at a March 20, 2006, meeting in New Orleans.

## OVERALL ASSESSMENT AND RECOMMENDATIONS

The IPET has made progress on several fronts and deserves credit for these advances, especially given the constraints and pressures under which IPET members are working. Nevertheless, a significant amount of work remains to be done if a credible, systemwide view of the impacts to the hurricane protection system, its current status and vulnerabilities, and levels of future risk is to be produced.

The IPET second report is several hundred pages long and contains copious amounts of technical information. Although data-intensive and detailed studies are essential for a large-scale investigation like the IPET, the second report (which is essentially a data report) lacks integration and clarity. Introductory sections describe a set of objectives that are appropriate and useful; however, they do not explain clearly a systematic approach to the study, making it difficult to understand how subsequent chapters relate to one another and are to form a single, coherent document. Transitions between the chapters are not well explained, and individual chapters read primarily as stand-alone components that have little or no relation with other chapters in the report. These points are not merely cosmetic; they are of critical, material importance. A clearly written and well-organized report will be essential to communicate IPET findings to local, state, and federal officials, and others who will conduct long-range planning for a reconstituted hurricane protection system.

A primary concern with the IPET second report is the lack of a clear, systemwide picture of the New Orleans hurricane protection system (HPS) in terms of the five IPET study objectives. Specifically, the second report lacks a systemwide assessment of pre-Katrina design criteria and status, description of impacts on the system during and after the storm, societal consequences of Katrina-related damage, post-Katrina levels of vulnerability, and future levels of risk to the New Orleans region. A simple example is the need for clear statements that explain that the origins for hurricane protection system failures were at least twofold. First, the Katrina surge exceeded authorized levels of protection in some areas, leading to overtopping. Second, there were sites in the system where authorized levels of protection were not exceeded and overtopping did not occur, but where breaches occurred. Clearer statements on these topics will remove ambiguities and should make the IPET study more valuable in describing lessons learned and in making progress toward improved future hurricane protection systems and strategies.

June 1, 2006, is an important date in the context of New Orleans hurricane protection. This date heralds the beginning of the Atlantic hurricane season, and it is the date by which Task Force Guardian is to restore damaged hurricane protection structures to pre-Katrina levels. IPET's original schedule called for its final report to be issued on June 1, 2006. IPET has recently indicated, however, that the timeline for this final report will be extended, and plans now call for the June 1, 2006, report to be issued as a "draft final," with a final report to be issued after IPET has had further opportunity to consider input from this NAE/NRC committee and other groups and individuals.

This decision to allow the IPET additional time to complete its report is a welcome development and follows from recommendations in this committee's first letter report (issued on February 21, 2006). This schedule change is consistent with the nature of the IPET report, which will contain information that should serve as a basis for long-term planning relevant to New Orleans hurricane protection. Its principal value thus will be its use in longer-term planning decisions and not its application to immediate construction activities. This extended deadline will allow the IPET to take a more measured approach to its study, provide additional time for important data gathering and analysis, and offer IPET a greater opportunity to produce a comprehensive, credible set of reports on its important studies.

In addition to the March 20, 2006 briefing, the IPET provided a thorough briefing to this committee on May 15, 2006 in New Orleans (as this report was being reviewed and approved). At that meeting the IPET team explained that some useful investigations of levee breaches have disclosed important failure mechanisms that have not been considered in the previous design of New Orleans levees. Analyses of storm surge associated with Hurricane Katrina, which represent a useful effort toward quantifying hurricane hazards, and an update of progress by Task Force Guardian in repairing damaged sites throughout the hurricane protection system, were also explained. In its post-Katrina recovery and construction program, Task Force Guardian has understandably focused on repairing the most severe levee breaches and damaged parts of the hurricane protection system. Despite this important construction progress, emphasis on site-specific repairs and upgrades may be masking a broader appreciation of the true nature of risks to the entire New Orleans hurricane protection system, especially for the 2006 season.

With its low elevations, flat topography, and proximity to the Gulf of Mexico and the Mississippi River, the New Orleans region has always been vulnerable to storm surges and flooding. With population growth, urbanization, and the erosion of coastal wetlands, these vulnerabilities have increased over time; however, the hydrologic risks in the New Orleans region perhaps should have been better and more widely appreciated. It needs to be recognized that some degree of the region's vulnerability to flooding—even with additional structural protection—will remain.

To summarize this section:

- **The IPET second report contains shortcomings that will need to be addressed if the IPET final report is to provide credible science- and engineering-based findings that can serve as a basis for improving hurricane preparedness for the New Orleans region. The decision to issue the June 1, 2006, IPET report as a "draft final" provides additional time and a better opportunity to produce a more comprehensive, better organized, and more credible set of studies.**
- **Despite Task Force Guardian's progress in repairing damaged sections of the hurricane protection system, a broader appreciation of the true nature of hurricane risks to New Orleans, especially for the 2006 season, is still lacking.**

## SYSTEMWIDE EVALUATIONS

### Mapping and Visualization

More prominent use of geographic information systems (GIS) within the IPET initiative would help promote systemwide analysis, visualization, and communication. The IPET second report includes more maps than did its January report and therefore represents an advance in this regard. However, the report does not reflect progress in adopting an electronic mapping and visualization system as a unifying framework to promote regional spatial analysis. Such a framework would enhance understanding of underlying geology, elements of the system (e.g., levees, I-walls) and their interrelationships, and the condition of the entire, post-Katrina regional hurricane protection system. The use of GIS technology and approaches as an organizing framework for the IPET—rather than primarily using GIS-generated maps as illustrations to augment discussions—would help facilitate systemwide evaluation and presentation. Examples of regional maps that could be usefully displayed in a GIS format include soils, levees, authorized and existing levels of protection, and surge and wave conditions.

### Hurricane Storm Surge

The IPET has made excellent progress in modeling the large-scale hydrodynamics of Hurricane Katrina. With a focus on hindcasting Katrina impacts, useful advances have been made in reconstructing the atmospheric fields and simulating the surge and waves generated by these forcing fields. The simulated surge associated with Katrina compares well with observed high-water marks throughout the region, and reasonably well with hydrographs at the Inner Harbor Navigation Canal (IHNC) lock and at the entrance to the IHNC at Lake Pontchartrain. The waves compare well with measured data in the offshore region and Lake Pontchartrain.

There are several other observations regarding the status of this analysis. One is that although studies aimed at coupling the surge model and the wave model have begun, the impact of surge-wave interaction is yet to be quantified. A second observation is that the IPET second report does not discuss how the vertical datum information is incorporated into the wave analysis, or how it will be integrated with the surge analysis. A third observation is that studies of detailed hydrodynamics are focused on the 17th Street Canal, using three methods—physical modeling, engineering/empirical analysis, and numerical modeling; there is little evidence of any integration of these results. A fourth observation is that it would be useful to see results from model sensitivity tests to reasonable variations of model input data, model coefficients, and model formulation for various processes. Such sensitivity studies would help establish uncertainties inherent in the modeling and will be important prior to conducting design studies using these models.

## Conceptual Issues Associated with Hurricane Protection System Assessment

The concepts of "authorized level of protection" and "standard project hurricane" (SPH) are important to understanding the design and heights of levees in the New Orleans hurricane protection system as they existed before Katrina and as they performed during the storm. To the best of this committee's knowledge, the only reference within an official planning document explaining what constitutes the authorized level of protection is the language in Public Law 89-298, passed on October 27, 1965, which states that:

> The project for hurricane-flood protection on Lake Pontchartrain, Louisiana, is hereby authorized substantially in accordance with the recommendations of the Chief of Engineers in House Document 231, Eighty-ninth Congress, except that the recommendations of the Secretary of the Army in that document shall apply with respect to the Seabrook Lock feature of the project.

This very general language leaves a good deal of ambiguity regarding the precise level of protection that the hurricane protection system was designed to provide. A 1959 definition of standard project hurricane (SPH) was "the most severe storm that is considered reasonably characteristic of a region" (National Hurricane Research Project, 1959). That definition was incorporated into the 1965 House Document.

The IPET second report neither clearly summarizes these concepts nor explains how they have been equated to on-the-ground levee development as authorized and as existed pre-Katrina (height at construction minus subsidence). A clear understanding of these concepts is essential as a basis for addressing such questions as:

- What level of protection was afforded to New Orleans before Katrina?
- How was the SPH used to come up with the existing system design?
- Has the SPH been used with modern computer surge and wave modeling techniques to reassess the adequacy of this design? and
- How did Katrina compare to the SPH?

Partial answers to these questions can be found in Appendix A of House Document 231 in 1965 and in several subsequent design memoranda, but not all those documents are readily available to the public. Furthermore, extracting precise summaries of the procedures found in those documents—even for experts reasonably familiar with them—is difficult and time consuming.

## Geotechnical Investigations

In addressing geotechnical issues, the IPET second report does not exhibit an overall explanation of regional geology and soils, physical changes to the levee system over time, or the dynamics of the Mississippi River delta. Most discussion of levee performance in the IPET second report (Chapter VI; Appendixes K-1, K-2) focuses on the interpretation of the breach at the 17th Street Canal. More detailed information on area geology is presented (Appendix K-1 includes a reprint of a report by Dunbar et al., 1999)[2] together with local soil profiles, physical properties, and shear strength data.[3] However, the report does not address adequately physical changes and, in particular, ground subsidence. As a result of subsidence, the elevation of the top of a levee decreases, and the levee loses some of its capacity to protect against overtopping by flooding or storm surge. The alluvial system of the New Orleans region is subject to subsidence, some of it naturally occurring, some of it exacerbated by groundwater and oil extraction. This subsidence is pronounced in many areas of the New Orleans region and has reduced the heights of some levees and other structures.

Information about regional geology, including varying rates of subsidence across the region, is necessary to understand the status of the hurricane protection system before Hurricane Katrina, system performance during Katrina, and remaining risks and vulnerabilities. An emphasis on thorough documentation of geotechnical and soils studies will make it easier for other groups to apply IPET findings to long-range planning for the hurricane protection system.

## Status of the Post-Katrina System

The forces generated by Hurricane Katrina produced visible and invisible damage to the hurricane protection system. If the system is to be strengthened to protect against future hurricanes, structures that may have been weakened—but that may not appear to be damaged by visual inspection—must be identified and upgraded to at least withstand the forces they were designed to protect against. To date, the IPET analysis has focused on specific areas of failure, such as the 17th Street Canal breach.

Although it is important to understand the mechanisms of levee failures or overtoppings at specific sites, these past failures may not be strong predictors of points within the system that may be most stressed or fail in future events. Further, site-specific investigations are not being framed adequately as part of an evaluation of weaknesses and

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[2] Dunbar, J.B., V.H. Torrey, III, and L.D. Wakeley. 1999. A Case History of Embankment Failure, Geological and Geotechnical Aspects of the Celotex Levee Failure, New Orleans, Louisiana. Technical Report GL-99-11, Engineer Research and Development Center, Vicksburg, MS: Waterways Experiment Station.

[3] Other experts, such as those from the National Science Foundation study team, have been studying the local geology and construction history of the drainage canals.

vulnerabilities of the entire hurricane protection system. Thus, the IPET report contains little information to help answer crucial, systemwide questions, such as:

- How representative are these failure sites of other components of the levee system?
- What are the key vulnerabilities of existing structures within the protection system?
- What are the lessons learned that could reduce vulnerability of the levee system as it is being restored and enhanced? and
- For what storm conditions can the restored, enhanced system be expected to protect the city?

Ideally, a systemwide assessment would address:

1. Areas that might have failed if levee breaches elsewhere had not lowered water levels;
2. Areas that may become more prone to greater hydraulic loading if gates or other mechanisms are used to change locales that storm surges might enter;
3. Areas that were overtopped during Katrina and are now being repaired by Task Force Guardian; and
4. I-walls that were loaded to near capacity in Katrina and that may have been stressed but that did not fail.

The following bulleted items summarize the preceding section's main points:

- **To promote systemwide evaluation and communication, the IPET should explore ways to apply GIS more prominently as a unifying framework for its study. The IPET should also explore prospects of establishing a public website at which local and regional maps of soils, levees, and other relevant data can be accessed. GIS-based maps should also be used to portray other important aspects of the hurricane protection system, such as (1) authorized levels of protection across the system; (2) presently existing levels of protection across the system; and (3) plausible, worst-case surge and wave conditions across the system.**
- **Concepts of authorized level of protection and standard project hurricane should be clearly elucidated. The ultimate goal should be to explain how these concepts have been applied to levee design, and the levels of protection afforded by the hurricane protection system before and during Katrina.**
- **Considerable data gathering and analysis remains to be done if the IPET is to provide a systemwide, geotechnical analysis of the New Orleans hurricane protection system. Examples of these types of data include regional soils maps and soils profiles at select sites. More attention should be paid to the geology of the region, the history of levee construction, and how these two interact.**
- **Data should be gathered for those areas of the hurricane protection system that were loaded to near capacity by storm surges during Hurricane Katrina, and that may have been weakened but did not fail. Such information will assist the IPET in focusing protective measures on potentially vulnerable locations to prepare for the upcoming hurricane season.**

## THE 17TH STREET CANAL BREACH

The IPET second report proposes that the 17th Street Canal breach occurred when lateral water pressure was conveyed through a vertical gap formed between an I-wall in the levee and adjacent soil on the canal side of the levee. This caused displacement of the sheet pile and inboard soil by sliding on the lacustrine clay beneath the peat layer on-site. Sufficient evidence has been produced to identify the above loading and deformation condition as a valid failure mechanism. There are, however, limitations in the IPET analysis:

- The underlying mechanism of the gap that formed between the I-wall and adjoining, canal-side soil is not explained fully.
- The proposed failure mechanism—a circular arc failure surface with rigid body rotation—does not conform to the behavior observed in centrifuge tests conducted by a modeling team based at the Rensselaer Polytechnic Institute (RPI). Results from the RPI group show compression in the soils beyond the levee toe, followed by sliding along a nearly horizontal plane surface near the top of the clay.
- The report attempts to rationalize the timing of the breach with the measured storm surge records in the vicinity of the 17th Street Canal (this process is confused by the inconsistent use of NAVD88 and NGVD datums), but there remains a discrepancy between the observed and predicted surge heights at failure.

An additional limitation is that the undrained shear-strength data presented are not adequate for a reliable characterization of conditions at the 17th Street Canal breach. The shear-strength information is derived from piezocone penetrometer profiles[4] obtained at 20 locations in the vicinity of the breach (Figure VI-15 in the IPET second report), together with a variety of laboratory test data (principally unconsolidated triaxial shear tests: UU and UC tests[5]). The piezocone data were obtained as part of the postfailure investigation program. Sources of the laboratory test data are not clearly identified, and a significant fraction of these tests were apparently obtained as part of the original site investigation program for the floodwall design (ca 1989-1990). There is no quantitative assessment of sample and test quality. Measurements of undrained shear strength for each of the key low-permeability soil layers comprising compacted fill, marsh, peat, and lacustrine clay units are aggregated. Comparisons of strength data from the east (breached) and west sides of the 17th Street Canal and for locations beneath the crest and beneath the toe of the levee have not been made.

These data presented in the IPET second report do not form an adequate basis for establishing the "IPET shear strength model"/profiles presented in Figures K1-54, K1-55 and K1-56 of the IPET second report. In particular, adequate documentation to confirm the shear-strength profile expected at the toe of the levee or to establish underlying trends in spatial variability is not provided. There are no data to substantiate statements that the shear strengths are generally higher to the north and south of the breached section.

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[4] These profiles are from cone penetration tests that measure pore water pressure at one or several locations on the penetrometer surface. This testing provides a more reliable determination of soil stratification, strength, and type than standard cone penetration tests (CPT).
[5] UU: unconsolidated undrained; UC: unconfined compression.

Given the variable data reported, alternative laboratory testing procedures that can achieve higher-quality measurements of shear strength should be used. This committee's February 21, 2006, report recommended consolidated, undrained direct-simple-shear (DSS) testing using SHANSEP protocols (Ladd and Foott, 1974[6]) to minimize effects of sample disturbance. These techniques have been extensively validated in the same locale (Ladd et al., 1972[7]; Fuleihan and Ladd, 1976[8]). This committee also recommended field vane-shear (FVS) tests to supplement in situ estimates of strength from piezocone soundings. However, there is little evidence that these tests and interpretation procedures have been incorporated into the IPET investigation. At the March 20, 2006, meeting, IPET representatives stated that DSS tests had been commissioned and that FVS tests were planned. No further information about either the test programs or the schedule for completion was provided.

For all these reasons, a convincing case has not yet been made that the IPET has identified the critical mechanism that directly caused the 17th Street Canal levee breach. Other viable failure mechanisms are possible, including sliding in clay with strength lower than currently characterized, sliding within the peat layer, and 3-D progressive failure of the levee toe.

The probability of failure as determined in the IPET second report assumes that a mean value applies at the locations of potential failure. In reality, undrained strength varies spatially, and a process for addressing its spatial variability should be developed. Such an approach would ideally determine for each representative length of levee a soil strength for which the frequency or probability of exceedance is larger than some specified level, consistent with acceptable project risk. The IPET second report describes no effort to address these statistical and probabilistic issues.

It is important for the IPET to integrate the results of field observations, limiting equilibrium analyses (using both circular and planar sliding surfaces), finite element simulations, and centrifuge tests to show the most likely failure mechanisms in a more convincing way, with greater consistency among the physical and analytical models, field data, and failure observations on-site. The IPET should also consider the emerging results from the study being conducted by scientists sponsored by the National Science Foundation. Moreover, the IPET team should be aware of alternative failure mechanisms and assess the potential for instability at other locations along the levee system, using all failure mechanisms that are appropriate for the soil conditions and levee geometry at hand.

The following bulleted items summarize the preceding section's key points:

- **The explanation of the failure mechanism for the 17th Street Canal breach, while plausible, is not fully convincing, and alternative failure mechanisms should**

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[6] Ladd, C.C., and R. Foott. 1974. New Design Procedure for Stability of Soft Clays. Journal of the Geotechnical Division, ASCE 100 (GT7) July:763-786.

[7] Ladd, C.C., C.E. Williams, D.H Connell, and L. Edgers. 1972. Engineering properties of soft foundation clays at two South Louisiana levee sites. Research Report R72-26. Department of Civil Engineering. Cambridge, MA: Massachusetts Institute of Technology.

[8] Fuleihan, N.F., and C.C. Ladd. 1976. Design and performance of Atchafalaya flood control levees," MIT Research Report R 76-24 (2 Vols.), Dept. Civil Engineering, Cambridge, MA: Massachusetts Institute of Technology.

**be more rigorously assessed. The IPET should assess the potential for instability at other locations along the hurricane protection system, using all failure mechanisms that are appropriate for the soil conditions and levee geometry at hand. The IPET final report should also address the statistical and probabilistic procedures for characterizing the variability of soil conditions throughout the hurricane protection system.**

- **Carefully executed direct-simple-shear (DSS) and field-vane-shear (FVS) tests should be performed at the 17th Street Canal breach site as soon as practicable. Results from these tests should be integrated with previously acquired strength data, using interpretation procedures that account for stress history and in situ stress. The IPET should also consider the results being produced by the scientists sponsored by the National Science Foundation. An assessment of data reliability should be provided as part of these tests, and the most reliable data should be given preference in the interpretation process.**

## HURRICANE PROTECTION SYSTEM: RISK AND RELIABILITIES

Chapter 8 on "Risk and Reliability" from the IPET second report is intended to synthesize and integrate all of the IPET findings. The analyses in this section are complicated by several methodological challenges, which fall into three categories: (1) large uncertainties surrounding estimates of probabilities associated with stresses placed upon the hurricane protection system; (2) the difficulty of estimating failure probabilities due to spatial heterogeneity of the stresses placed on the existing hurricane protection system; and (3) vulnerability of a very large number of components of the hurricane protection system.

Although the risk and reliability chapter is in its initial stages of development, the methods used in the hazard hurricane modeling have not been clearly explained or justified, are complicated, and contain substantial uncertainties. *This is a significant problem given the possibility that these analyses will serve as the basis of re-occupying the region and designing modifications to the hurricane protection system.*

### Hurricane Return Probabilities

The IPET proposes communicating to the public the degree of hazard associated with hurricanes in terms of annual probabilities and return periods. It thus would be helpful to explain that these annual measures provide only a partial measure of the long-term vulnerability of a given site or city to hurricane hazards. For example, for a 100-year storm there is an 18 percent probability that at least one storm of that magnitude or greater will affect a given site in the next 20 years, and a 40 percent probability that at least one storm of that magnitude or greater will affect a given site in the next 50 years. For a 400-year storm, there is a 12 percent probability that at least one storm of that magnitude or greater will affect a given site over a 50-year time horizon. These probabilities of catastrophic storms are not insignificant when a metropolitan area of more than one million people is at risk. Given the importance of planning hurricane protection systems on these longer time scales, it is crucial to consider not only a given storm's annual recurrence probability, but also its probability of recurring on time horizons longer than one year.

The most critical stresses associated with hurricanes are water levels resulting from storm surge and waves, although wave energy can also be important. The stresses that affect a hurricane protection system depend on storm parameters (e.g., wind speed, storm size, central pressure, track, forward speed) as well as on the response of coastal waters to the storm. Although a reasonable capability has been demonstrated in modeling the response of the coastal waters to specific historical storms, there are no widely accepted methods for estimating the probability distribution of stresses placed upon the hurricane protection system. Estimates of risk and reliability are therefore potentially controversial and highly uncertain.

The IPET report provides only scant details of the procedures to generate these estimates. Of particular concern is the interdependency among hurricane parameters and how these can be incorporated into a joint probability distribution. Enough is known about probability distributions for hurricanes to know that, with the relatively small number of observations of hurricanes in the vicinity of New Orleans, any assignment of probabilities to individual hurricanes will include considerable uncertainty. It thus is important to consider carefully the full suite of storms, especially the larger ones, in generating the probability distribution of hurricanes that may affect the New Orleans region.

As part of assigning probabilities associated with future hurricanes, the IPET should review historical storms in the Gulf of Mexico region and place these storms, and the standard project hurricane, in the context of the IPET probabilistic analysis. A description of the history of hurricanes in the Gulf Coast region would also be valuable in helping analysts, decision makers, and the public better understand the nature of hurricane strengths, variations, storm tracks, probabilities, and recurrence intervals. That history should consider the strong hurricanes that affected the Gulf coastal region in 2004-2006 and what this recent activity implies for future hurricane strength, return intervals, and hurricane preparedness.

## Risks to the Hurricane Protection System

The strength and reliability of a protection system to catastrophic failure depends on the integrity of its many different components. A hurricane protection system is analogous to a chain with multiple links. An estimate of the probability that the chain breaks under a specified stress requires an estimate of the probabilities that any link, or protection structure, will break when subjected to the same stress. Furthermore, the failure probability of the chain is larger than the failure probabilities of the individual links, meaning that accurate estimation of the probability of chain failure requires estimation of very low probabilities associated with the failure of links. For example, in the case of a chain with 1,000 links, each with a failure probability of .001 percent, the failure probability of the chain is about 1 percent. Because system failure can result from a breach or overtopping at one of many thousands of locations, estimates of the magnitude of storm surge stresses and of hurricane protection system strengths at many different points are required for a comprehensive evaluation of system reliability.

The IPET proposes to estimate reliability of the hurricane protection system under several different conditions, including the authorized level(s) of protection, pre-Katrina conditions, with post-Katrina repairs (up to June 1, 2006), and with post-Katrina repairs and improvements fully implemented. This assessment is to be accomplished by using a risk analysis approach that is based on a joint probability analysis. A spreadsheet template has been developed and tested to combine hurricane probabilities, system reliability, and consequences. A wide suite of physical parameters associated with hurricanes will be provided from an ensemble of over 1,000 hurricanes, each of which drives a storm surge model run using the Advanced Circulation (ADCIRC) model. Probabilities of occurrence will be assigned to each hurricane in the ensemble. Other events that could contribute to failure will also be identified (IPET, 2006, Figure J-6). Probabilities of these other events will, in turn, be combined with hurricane stress probabilities to calculate probabilities of hurricane protection system failure for each hurricane. Consequences of each hurricane will be calculated, thereby generating a probability distribution of consequences. Although these procedures appear to follow well-established frameworks for estimating risks and reliability, it is not at all clear that they will produce credible results. *It will be difficult and challenging for the IPET to develop a robust and defensible assessment of the risk and reliability of the hurricane protection system using its current approach.*

The credibility of this integrative component of the IPET study will depend on IPET's ability to explain and validate its methods for establishing the probabilities of failure of individual components of the protection system, as well as overall system performance. The difficulties associated with making these various assessments should not be understated, and uncertainties within these estimates should be treated openly and candidly. For example, the assignment of probabilities and return intervals to the standard project hurricane in U.S. House Document 231 in 1965, and in subsequent modifications, is made by simple assertion rather than upon science-based information. Given the small number of events for which complete information is available, there are limits on the reliability of these assigned probabilities.

The validity of these probabilities underlies this entire risk analysis approach. It therefore is crucial that a discussion and evidence supporting the assignment of probabilities be featured prominently within the IPET reports in user-friendly language and figures, and not framed within technical language of probability functions. Given these analytical challenges and complications, it is difficult to envision the chapter on risk and reliability providing anything but rudimentary characterizations of systemwide risk and reliability—with considerable levels of uncertainty—by June 1, 2006. The extension of the deadline for the IPET final report, however, provides additional time to produce better-developed characterizations.

The IPET should also consider conducting a simpler, deterministic assessment of storm surge potential based on a smaller set of storms selected to establish a realistic baseline for inundation potential over a range of critical storm parameters, such as storm intensity, storm size, approach speed and direction, and the intersection of the track line with the coast. By varying these storm parameters it should be possible to identify potential surge and wave conditions applicable to the various parts of the hurricane protection system. This assessment could include worst-case scenarios based on a category 5 storm to assess the adequacy of the present design and capability of the hurricane protection system. Rather than ~1,000 model runs, this approach could be conducted with about 50 runs. This deterministic assessment could also be used to address future design considerations, including proposed levee height increases, new levee construction, and the effects of wetlands on surge heights. Although this exercise by itself may not lead to a specific probabilistic statement of risk, it will provide a better understanding of surge and wave response potentials for a representative set of hurricanes. This approach is likely to be more valuable for assessing the near-term state of the hurricane protection system than a highly questionable probabilistic analysis.

The following bulleted items summarize the preceding section's key points:

- **The IPET should provide a history of hurricanes in the Gulf of Mexico and place the major storms (e.g., Betsy, Camille, Katrina), and the SPH, in the context of the IPET probabilistic analysis.**
- **The IPET should provide a thorough and understandable explanation of the method being used in the assessment of the risk and reliability of the hurricane protection system. Evidence should be presented that validates the probabilities being assigned to various parts of the system. A clear discussion that identifies the level(s) of uncertainty associated with these results should be part of this explanation.**
- **The lack of estimates of the potential for inundation in the New Orleans region in the upcoming hurricane season represents a shortcoming in the IPET second report. To enhance future hurricane preparedness, the IPET should provide two separate but related sets of estimates of surge and wave levels at various locations across the hurricane protection system. The first is a deterministic set of inundation analyses based on a relatively small set (e.g., ~50) of representative storms that includes a worst-case scenario. The second entails joint analyses of probability of occurrence for a given storm, along with probability of occurrence of specific hurricane protection system failure modes. The first identifies the potential for risk; the second attempts to quantify this.**
- **The IPET should not expect to—nor be expected to—obtain credible estimates of risk by June 1, 2006. At best, results from this portion of the IPET effort will give some indication of relative risks associated with the scenarios considered and will aid in identifying critical vulnerabilities. Although the extension of the deadline for the IPET final report will allow additional time for these analyses, the IPET risk and reliability effort should be considered only as the first step in a long-term effort to develop and apply an accepted method for hurricane risk assessment.**

## CLOSING COMMENTS

The IPET studies of the New Orleans regional hurricane protection system are unique not only for their ambitious scope but also for the level of scrutiny and political pressure under which the IPET is operating. Under these circumstances, IPET scientists and engineers are motivated to advance quickly and produce a report that contains as much data and supporting information as practicable. It nevertheless is important that efforts be focused on ensuring that the study's components form an integrated and unified work plan and study. We encourage the IPET to remain focused on the study's overall objectives and in explaining how the different datasets, models, and applications will eventually result in an integrated study of the New Orleans hurricane protection system, and not just select portions of that system.

Public education of the risks of hurricanes and storm surge is an important component of overall hurricane preparedness. Although the IPET and the Corps of Engineers of course cannot be responsible for all efforts to inform people about risks associated with hurricanes and flooding in the New Orleans region, public officials and citizens clearly look to the IPET and the Corps for leadership on these issues. This committee thus encourages the IPET and Corps to use their considerable knowledge of these topics to help inform the public and elected officials, and thereby enhance hurricane preparedness in the New Orleans region for both the current and for future hurricane seasons.

The following list summarizes this report's primary findings and recommendations:

- **The IPET second report contains shortcomings that will need to be addressed if the IPET final report is to provide credible science- and engineering-based findings that can serve as a basis for improving hurricane preparedness for the New Orleans region. The decision to issue the June 1, 2006, IPET report as a "draft final" provides additional time to produce a more comprehensive and credible set of studies.**
- **Despite Task Force Guardian's progress in repairing damaged sections of the hurricane protection system, a broader appreciation of the true nature of hurricane risks to New Orleans, especially for the 2006 season, is still lacking.**
- **To promote systemwide evaluation and communication, the IPET should explore ways to apply GIS more prominently as a unifying framework for its study, as well as explore the possibility of establishing a public website at which regional maps of soils, levees, and other relevant data can be accessed. GIS-based maps should also be used to portray other important aspects of the hurricane protection system, such as (1) authorized levels of protection across the system, (2) presently existing levels of protection across the system; and (3) plausible, worst-case surge and wave conditions across the system.**
- **Concepts of authorized level of protection and standard project hurricane should be clearly elucidated. The ultimate goal should be to explain how these concepts have been applied to levee design, and the levels of protection afforded by the hurricane protection system before and during Katrina.**
- **Considerable data gathering and analysis remains to be done if the IPET is to provide a systemwide geotechnical analysis of the New Orleans hurricane protection system. More attention should be paid to the geology of the region, the history of levee construction, and how these two interact.**
- **Special emphasis should be placed on gathering data for those areas of the hurricane protection system that were loaded to near capacity by storm surges**

**during Katrina, and that may have been weakened but did not fail, as it will be important for IPET to provide information regarding levels of protection of the system for the upcoming hurricane season.**

- **The explanation of the failure mechanism for the 17th Street Canal breach, while plausible, is not fully convincing. Alternate failure mechanisms should be more rigorously assessed. The IPET should assess the potential for instability at other locations along the hurricane protection system.**
- **Carefully executed direct-simple-shear (DSS) and field-vane-shear (FVS) tests should be performed at the 17th Street Canal breach site as soon as practicable. Results from these tests should be integrated with previously acquired strength data. The IPET should also consider the results from the study conducted by a team of scientists sponsored by the National Science Foundation.**
- **The IPET should provide a history of hurricanes in the Gulf of Mexico and place the major storms (e.g., Betsy, Camille, Katrina), and the SPH, in the context of its probabilistic analysis.**
- **The IPET should provide a thorough and understandable explanation for the method being used in its assessment of risk and reliability of the hurricane protection system. Evidence should be presented that validates the probabilities that are being assigned the various parts of the system. A clear discussion that identifies the level(s) of uncertainty associated with these results should be part of this explanation.**
- **The IPET should provide two separate but related sets of estimates of hurricane wave levels at various locations. The first is a deterministic set of inundation analyses based on a relatively small set (e.g., ~50) of representative storms that include a worst-case scenario. The second entails joint analyses for probability of occurrence for a given storm along with the probability of occurrence of specific hurricane protection system failure modes.**
- **The IPET should not expect to—nor be expected to—obtain credible estimates of risk by June 1, 2006.**

## APPENDIX A
## STATEMENT OF TASK
## COMMITTEE ON NEW ORLEANS REGIONAL HURRICANE PROTECTION PROJECTS

Hurricane Katrina and the subsequent flooding of much of the New Orleans metro area prompted many questions about the geotechnical and hydraulic conditions and performance of the city's hurricane protection system. To help provide credible scientific and engineering answers regarding the performance of this system, an Interagency Performance Evaluation Task Force (IPET) has been convened. The IPET effort is being led by the U.S. Army Corps of Engineers. The IPET is also working with a review team from the American Society of Civil Engineers (ASCE). The IPET, which includes both federal and non-federal scientists and engineers, is divided into ten teams focusing on different topical areas*. The IPET is focusing its investigation on 3 primary topics: a) design capacity of the hurricane protection system, b) forces exerted against the system and system response, and c) factors that resulted in overtopping, breaching, or failure of levees and floodwalls. The IPET report on the structural performance of the hurricane protection system is due on May 1, 2006 (the final IPET report on the entire study is due on June 1, 2006).

This NRC/NAE committee will focus its review on the following tasks:

1) review the data gathered by the IPET and the ASCE teams and provide recommendations regarding the adequacy of those data, as well as additional data that will be important to the IPET study and should be gathered;

2) review the analyses performed by the IPET and ASCE to ensure their consistency with accepted engineering approaches and practices;

3) review and comment upon the conclusions reached by the IPET and ASCE teams, and;

4) seek to determine lessons learned from the Katrina experience and identify ways that hurricane protection system performance can be improved in the future at the authorized level of protection.

The NRC/NAE committee will issue three reports:

1) a preliminary, letter report that comments on the adequacy of the nature of the data being collected by the IPET and ASCE teams (due in February 2006);

2) an interim report that represents the midpoint of the committee's evaluation and project (due June 1, 2006), and;

3) a final, comprehensive report (due in September 2006) that summarizes the committee's evaluation of the IPET/ASCE report on structural performance of the hurricane system.

The timeline for these three NRC/NAE reports conforms to plans regarding IPET report progress. IPET reporting meetings are scheduled for January 2006 (30%), March 2006 (60%), and May 2006 (90%). The first two NRC/NAE reports will be drafted and issued following the review and evaluation of the IPET 30% and 60% completion reports, respectively. The third NRC/NAE report will be based upon the IPET/ASCE report (due May 1, 2006) on structural performance of the hurricane protection system.

*The committee’s review will focus on the analyses of IPET teams in the areas of: data collection and management (perishable, systems data, and information management), interior drainage systems models, numerical models of the Hurricane Katrina surge and wave environment, storm surge and wave physical modeling of hydrodynamic forces and centrifuge breaching, geodetic vertical survey assessment, and the analysis of floodwall and levee performance.

# APPENDIX B
# COMMITTEE ON NEW ORLEANS REGIONAL HURRICANE PROTECTION PROJECTS

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## APPENDIX C
## ACKNOWLEDGEMENT OF REVIEWERS

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with the procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report: John J. Cassidy, Bechtel Corporation (retired); Robert A. Dalrymple, Johns Hopkins University; David T. Ford, David Ford Consulting Engineers; Walter R. Lynn, Cornell University; Henry G. Schwartz, Jr., Washington University; Nicholas Sitar, University of California, Berkeley; Edward Wenk, Jr., University of Washington (emeritus), and; Robert V. Whitman, Massachusetts Institute of Technology.

Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Robert A. Frosch, Harvard University, who was appointed by the NRC's Report Review Committee, and by Stephen P. Leatherman, who was appointed by the NRC's Division on Earth and Life Studies. Drs. Frosch and Leatherman were responsible for ensuring that an independent examination of this report was conducted in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for this report's final content rests entirely with the authoring committee and the institution.